Claims

We claim:

1. A method of forming a ruthenium film, comprising the steps of:

reacting a ruthenium source gas and oxygen at a first pressure and at a first oxygen gas flow rate to deposit ruthenium on a substrate; and

reacting the ruthenium source gas and oxygen at a second pressure and at a second oxygen gas flow rate to deposit ruthenium on the substrate, wherein at least one of the second pressure and the second oxygen gas flow rate is less than the first pressure and the first oxygen gas flow rate, respectively.

2. A method as recited in Claim 1, wherein the first pressure is in a range from about 10 Torr to 50 Torr.

3. A method as recited in Claim 1, wherein the second pressure is in a range from about 0.05 Torr to 10 Torr.

4. A method as recited in Claim 1, wherein the first oxygen gas flow rate is in a range from about 500 sccm to 2000 sccm.

5. A method as recited in Claim 1, wherein the second oxygen gas flow rate is in a range from about 10 sccm to 300 sccm.

6. A method as recited in Claim 1, wherein a substrate temperature is in a range from about 250° C to 450° C.

7. A method as recited in Claim 6, wherein the substrate temperature is about 10° C to about 30° C higher when performing the step of reacting the ruthenium source gas and oxygen at the second pressure and at the second oxygen gas flow rate than the substrate temperature is when performing the step of reacting the ruthenium source gas and oxygen at the first pressure and at the first oxygen gas flow rate.

8. A method as recited in Claim 1, further comprising the step of:

heating the deposited ruthenium at a temperature in a range from about 250° C to 450° C in an atmosphere that comprises a gas selected from the group consisting of oxygen and ozone after the step of reacting the ruthenium source gas and oxygen at the first pressure and at the first oxygen gas flow rate.

9. A method as recited in Claim 8, wherein the step of heating the deposited ruthenium at the temperature in the range from about 250° C to 450° C in the atmosphere that comprises the gas selected from the group consisting of oxygen and ozone comprises the step of:

heating the deposited ruthenium at the temperature in the range from about 250° C to 450° C in the atmosphere that comprises the gas selected from the group consisting of oxygen and ozone at a CVD chamber pressure in a range from about 1 to 100 Torr.

10. A method as recited in Claim 1, further comprising the step of:

heating the deposited ruthenium at a temperature in a range from about 250° C to 450° C in an atmosphere that comprises a gas selected from the group consisting of oxygen and ozone after the steps of reacting the ruthenium source gas and oxygen at the first pressure and at the first oxygen gas flow rate and reacting the ruthenium source gas and oxygen at the second pressure and at the second oxygen gas flow rate.

11. A method as recited in Claim 10, wherein the step of heating the deposited ruthenium at the temperature in the range from about 250° C to 450° C in the atmosphere that comprises the gas selected from the group consisting of oxygen and ozone comprises the step of:

heating the deposited ruthenium at the temperature in the range from about 250° C to 450° C in the atmosphere that comprises the gas selected from the group consisting of oxygen and ozone at a CVD chamber pressure in a range from about 1 to 100 Torr.

12. A method as recited in Claim 1, wherein the ruthenium source gas is selected from the group consisting of vaporized $Ru(C_2H_5C_5H_4)_2$

(Bis(EthylCyclopentadienyl) Ruthenium), $Ru(C_{11}H_{10}O_2)_3$ (Tris(DiPivaloylMetanate) Ruthenium), $Ru(C_5H_5)_2$ (Bis(Cyclopentadienyl) Ruthenium), and $Ru(CH_3CH_2CH_2CH_2CH_3C_5H_3)_3$ (Tris(2, 4-OctaneDionato) Ruthenium).

13. A method of forming a ruthenium film, comprising the steps of:

reacting a ruthenium source gas and oxygen to deposit ruthenium on a substrate; and

changing at least one of a pressure, an oxygen gas flow rate, and a substrate temperature during the step of reacting the ruthenium source gas and oxygen.

14. A method as recited in Claim 13, wherein the step of changing at least one of the pressure, the oxygen gas flow rate, and the substrate temperature comprises the step of:

decreasing the pressure from a range of about 10 to 50 Torr to a range of about 0.05 to 10 Torr.

15. A method as recited in Claim 13, wherein the step of changing at least one of the pressure, the oxygen gas flow rate, and the substrate temperature comprises the step of:

decreasing the oxygen gas flow rate from a range of about 500 to 2000 sccm to a range of about 10 to 300 sccm.

16. A method as recited in Claim 13, wherein the step of changing at least one of the pressure, the oxygen gas flow rate, and the substrate temperature comprises the step of:

increasing the substrate temperature by an amount ranging from about 10° C to 30° C while maintaining the substrate temperature in a range from about 250° C to 450° C.

17. A method as recited in Claim 13, wherein the ruthenium source gas is selected from the group consisting of vaporized $Ru(C_2H_5C_5H_4)_2$ (Bis(EthylCyclopentadienyl) Ruthenium), $Ru(C_{11}H_{10}O_2)_3$ (Tris(DiPivaloylMetanate)

Ruthenium), $Ru(C_5H_5)_2$ (Bis(Cyclopentadienyl) Ruthenium), and $Ru(CH_3CH_2CH_2CH_2CH_3C_5H_3)_3$ (Tris(2, 4-OctaneDionato) Ruthenium).

18. A method of forming a ruthenium film, comprising the steps of:

forming the ruthenium film on a substrate such that the ruthenium nucleation rate is greater than the ruthenium growth rate; and

forming the ruthenium film on the substrate such that the ruthenium growth rate is greater than the ruthenium nucleation rate.

19. A method as recited in Claim 18, further comprising the step of:

heating the ruthenium film at a temperature in a range from about 250° C to 450° C in an atmosphere that comprises a gas selected from the group consisting of oxygen and ozone after the step of forming the ruthenium film on the substrate such that the ruthenium nucleation rate is greater than the ruthenium growth rate.

20. A method as recited in Claim 19, wherein the step of heating the ruthenium film at the temperature in the range from about 250° C to 450° C in the atmosphere that comprises the gas selected from the group consisting of oxygen and ozone comprises the step of:

heating the ruthenium film at the temperature in the range from about 250° C to 450° C in the atmosphere that comprises the gas selected from the group consisting of oxygen and ozone at a pressure in a range from about 1 to 100 Torr.

21. A method as recited in Claim 18, further comprising the step of:

heating the ruthenium film at a temperature in a range from about 250° C to 450° C in an atmosphere that comprises a gas selected from the group consisting of oxygen and ozone after the steps of forming the ruthenium film on the substrate such that the ruthenium nucleation rate is greater than the ruthenium growth rate and forming the ruthenium film on the substrate such that the ruthenium growth rate is greater than the ruthenium nucleation rate.

22. A method as recited in Claim 21, wherein the step of heating the ruthenium film at the temperature in the range from about 250° C to 450° C in the atmosphere that comprises the gas selected from the group consisting of oxygen and ozone comprises the step of:

heating the ruthenium film at the temperature in the range from about 250° C to 450° C in the atmosphere that comprises the gas selected from the group consisting of oxygen and ozone at a pressure in a range from about 1 to 100 Torr.

23. A ruthenium film, comprising:

a ruthenium layer having a stratified oxygen concentration.

24. A ruthenium film as recited in Claim 23, wherein the ruthenium layer has an oxygen concentration profile that substantially approximates a step function.

25. A ruthenium film, comprising:

a ruthenium layer having a stratified nucleation.

26. A method of forming an integrated circuit device, comprising the steps of:

forming a lower electrode on a substrate;

forming a dielectric layer on the lower electrode; and

forming an upper electrode on the dielectric layer;

wherein at least one of the lower electrode and the upper electrode comprises a ruthenium film formed by the following steps:

forming the ruthenium film by chemical vapor deposition (CVD) using a ruthenium source gas and oxygen as a reactant gas at a first CVD chamber pressure and at a first oxygen gas flow rate; and

forming the ruthenium film by CVD using the ruthenium source gas and oxygen as the reactant gas at a second CVD chamber pressure and at a second oxygen gas flow rate, wherein at least one of the second CVD chamber pressure and the second oxygen gas flow rate is less than the first CVD chamber pressure and the first oxygen gas flow rate, respectively.

27. A method of forming an integrated circuit device, comprising the steps of:

forming a lower electrode on a substrate;

forming a dielectric layer on the lower electrode; and

forming an upper electrode on the dielectric layer;

wherein at least one of the lower electrode and the upper electrode comprises a ruthenium film formed by the following steps:

forming the ruthenium film by chemical vapor deposition (CVD) using a ruthenium source gas and oxygen as a reactant gas; and

changing at least one of a CVD chamber pressure, an oxygen gas flow rate, and the substrate temperature during the step of forming the ruthenium film.

28. A method of forming an integrated circuit device, comprising the steps of:

forming a lower electrode on a substrate;

forming a dielectric layer on the lower electrode; and

forming an upper electrode on the dielectric layer;

wherein at least one of the lower electrode and the upper electrode comprises a ruthenium film formed by the following steps:

forming the ruthenium film on a substrate such that the ruthenium nucleation rate is greater than the ruthenium growth rate; and

forming the ruthenium film on the substrate such that the ruthenium growth rate is greater than the ruthenium nucleation rate.